

**APPLICATION FOR UNITED STATES LETTERS PATENT**

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**TEST STRUCTURE FOR IMPROVED VERTICAL MEMORY ARRAYS**

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## TEST STRUCTURE FOR IMPROVED VERTICAL MEMORY ARRAYS

### BACKGROUND

#### Field of the Invention

[0001] The present invention relates generally to an integrated circuit architecture and more particularly to vertical transistor memories.

#### Background of the Invention

[0002] The continuing trend of size reduction of semiconductor memory components in products such as dynamic random access memory (DRAM) has led to development of vertical trench storage capacitors and more recently, vertical access transistors. Both devices are associated with the basic unit of a DRAM, the memory cell. An example of a DRAM cell based on a vertical access transistor is disclosed in U.S. Patent No. 5,519,236. Use of a vertical trench capacitor and a vertical access transistor facilitates the fabrication of a semiconductor memory cell where  $F=70$  nm or less, while at the same time making it possible to maintain the performance of the access transistor.

[0003] Such an integrated circuit architecture includes a transistor array comprising vertical FET transistors and storage capacitors formed vertically in deep trenches. Since the process for forming such devices is new, it is particularly desirable, during wafer processing and in general, to assess the properties and characteristic values of the selection transistors.

### SUMMARY

[0004] An exemplary embodiment of the present invention comprises a test structure for an integrated circuit architecture that provides for an assessment or a detection of

different characteristic values of a vertical FET transistor. In particular, a measurement is made of leakage currents and capacitances at junctions of the source and drain electrodes and at other interfaces. In order to be able to measure the buried structures, it is preferable that such a test structure provide access to the underside of the selection transistors via separate leads. Currentless and current-carrying access are preferably provided for in a separate fashion. In an exemplary embodiment, particular requirements of the new process which must be satisfied with regard to the word line concept, the formation of buried strips, and active webs can be assessed..

[0005] In accordance with an exemplary embodiment of the invention, a test structure is integrated into the integrated circuit arrangement, which test structure has, for the common connection of the drain terminals of a plurality of such vertical selection transistors, as first connecting means, in each case between two adjacent laterally offset selection transistors diagonally extended deep trenches filled with the conductive electrode material, the buried strip present there forming the drain electrodes of the adjacent vertical selection transistors at the intersection of the BS strip form with the extended deep trench. Preferably, the test structure is connected to a transistor array that comprises vertical FET selection transistors. The transistor array may be formed in a substrate in the form of parallel active webs made of semiconductor, arranged in a lateral direction of the circuit. The transistors may include drain terminals formed by conductive strips buried below the active webs, and gates formed by a spacer etched vertically at the side of the active webs. The buried strips in each case make contact with an electrode of a storage capacitor of a memory cell array assigned to the transistor array. The vertically etched spacer forms

a word line for the memory cells of the memory cell array, and each storage capacitor is formed in a deep trench, which in each case delimits on the end side a section of the active web that contains the vertical selection transistor, and which is filled with conductive electrode material.

[0006] An integrated circuit arrangement according to the one exemplary embodiment of the present invention has such a test structure that can be built on a wafer separately between the actual chips (between the products to be produced) by means of the same process.

#### **BRIEF DESCRIPTION OF THE DRAWINGS**

[0007] Figure 1 illustrates a diagrammatic cross section through a section of a known integrated circuit architecture with vertical FET transistors and storage capacitors formed in deep trenches.

[0008] Figure 2A illustrates a diagrammatic plan view of a section of a test structure according to an exemplary embodiment of the present invention, which provides a connection between two laterally offset vertical selection transistors by means of a deep trench extended diagonally between the transistors.

[0009] Figure 2B illustrates a cross-sectional view along the section line E-A of Figure 2A indicated by arrows depicting two vertical selection transistors connected back to back by a diagonally extended deep trench formed between them.

[0010] Figure 2C diagrammatically illustrates an equivalent circuit diagram with discrete elements of the section of the test structure illustrated in Figures 2A and 2B, including possibilities for connection of the vertical selection transistors that are connected to one another by the diagonally extended deep trench.

[0011] Figure 3A shows a diagrammatic plan view of a test structure in accordance with an exemplary embodiment of the present invention in which ten transistors are connected as test objects to one another.

[0012] Figure 3B illustrates an equivalent circuit diagram with discrete elements of the test structure shown in Figure 3A.

#### **DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS**

[0013] The following list of reference symbols is used consistently in the discussion to follow.

- 1 Source electrode (active web)
- 2 Channel-forming P-type region
- 3 Drain electrode (buried strip DS)
- 5a Section of the gate electrode (word line WL)
- 6 Capacitor electrode
- 8, 8a, 8b Insulating layers
- 9 Dielectric
- 10 Substrate
- AT Active Web
- BL Bit line
- CB Contact to the bit line (source contact)
- BS Buried conductive strip
- DT Extended deep trench or zigzag deep trench
- A Output through CB from the bit line BL
- E Input through CB to the bit line BL
- DUT Device under test
- M0 Metal plane 0

[0014] Before describing the preferred embodiments of the present invention, a known transistor array based on U.S. Patent No. 5,519,236, which contains vertical field effect transistors will be described with reference to Figure 1.

[0015] The accompanying Figure 1 diagrammatically shows a cross section through a section of a known integrated circuit architecture, through one of the active webs forming the active semiconductor regions. In a corresponding process, bulk, source and drain electrodes of the FET selection transistors are formed in the silicon-filled active webs. Figure 1 shows two adjacent transistor sections of the FET selection transistors, which, in the active web sections, have an  $n^+$ -type source region 1, a channel-forming p-type region 2 and an  $n^+$ -type drain electrode 3 formed by means of a buried strip. Figure 1 also shows two storage capacitors which are formed in a deep trench and are in each case represented by a capacitor electrode 6 (for example made of polysilicon) and an insulating dielectric 9. The capacitor electrode 6 of the storage capacitors is in contact via a conductive section 7 with the drain electrode 3 (buried strip) of the an associated selection transistor.

[0016] Figure 1 also shows insulating layers 8, 8a, and 8b in each case for the insulation of the end-side sections 5a of peripheral gate electrode strips from channel-forming p-type regions 2 and drain electrode 3, on the one hand, and from conductive capacitor electrode section 6, on the other hand. The gate electrode strip, which is situated at the sides of the active web and of which only the transversely running section 5a can be seen in Figure 1, simultaneously serves as a word line for the memory cell array assigned to the transistor array. Furthermore, source electrode 1,

represented as a covering layer in Figure 1, serves for producing a source terminal of the vertical FET transistors with an assigned bit line (not shown).

[0017] Figure 2A illustrates a test structure according to an exemplary embodiment of the present invention, which connects in each case two adjacent and laterally offset vertical FET selection transistors. The illustration shows a plurality of vertical active webs (AT) 200, which have word lines (WL) 202 in each case on both sides, horizontally parallel-running bit lines (BL) 204 and buried conductive strips (BS) 206, which are formed where a BS mask (not shown) intersects a deep trench (DT) 208 (Figure 2B). As explained with reference to Figure 1, the drain electrodes of the vertical transistors or the buried drain contacts cannot be directly accessed from outside.

[0018] An exemplary embodiment of the present invention includes an integrated test structure as illustrated in Figures 2A-2C, that forms a "back to back" connection between in each case two adjacent, laterally offset vertical selection transistors, since the buried drain electrodes (formed at the intersection of the BS shape with the deep trench 208 and the active web 200) are not accessible in such a vertical transistor. Figure 2A shows four pairs of FET selection transistors that are connected to one another by the diagonal DT sections. In order to produce this connection, the integrated test structure includes diagonally extended deep trenches DT filled with the conductive electrode material acting as a first connecting means between in each case two paired laterally offset FET selection transistors. A second connecting means, namely source contacts (CB) 210, connect the test structure thus formed to separate

bit lines BL at points which are identified in each case by E and A in Figures 2A and 2B.

[0019] Figure 2B shows a diagrammatic cross-sectional view through a section of Figure 2A with two vertical selection transistors connected back to back in this way. The section line running between E and A is indicated by arrows in Figure 2A. Figure 2B clearly shows that FET selection transistors 220 (1st transistor (left), and 222 (2nd transistor (right) are connected to one another back to back via their drain electrodes by an extended deep trench 208. Like the storage capacitors described above with reference to Figure 1, deep trench 208 is filled with conductive electrode material, for , with polysilicon. The current path passes from the CB contact designated by E through first transistor 220 (left) into the polysilicon of the deep extended trench 208 and then through the second transistor 222 (right) to a CB contact 210 thereof, indicated by A. As mentioned, the CB contacts E and A of first and second selection transistors, 220 and 222, respectively, are in each case connected to a separate bit line BL (not shown).

[0020] Furthermore, as illustrated in Figure 2a, selection transistors 220 and 222 are connected to separate word lines WL, which enable an independent control of the gates of the two selection transistors.

[0021] Figure 2C depicts an equivalent circuit diagram of the test structure illustrated in Figures 2A and 2B with discrete elements. From the input E connected to a bit line 204 the current path passes through a CB contact 210, left-hand vertical selection transistor 220, a left-hand buried strip (RBS) 224, the diagonally extended deep trench 208, a right-hand buried strip 226, right-hand vertical selection transistor 222,

a right-hand CB contact 210' to the output A, which is connected to a second parallel bit line 204'. A second pair of vertical selection transistors 228 and 230 that are connected to one another in this way is connected to the same bit lines BL-i204,204'. As mentioned above, in principle the gates of the transistors 220 and 222 can be controlled independently of one another by separate word lines, indicated by way of example by WL 232 and WL 234 in Figure 2C. The same applies to the interconnected pair of selection transistors 228 and 230 whose gates can be controlled independently of one another by separate word lines 236 and 238.

[0022] Figure 2C uses broken lines to show a possibility for connecting the word lines 232 and 236 of the respective left-hand vertical selection transistors 220 and 228, to one another, and word lines 234 and 238 of the respective right-hand vertical selection transistors 222 and 230 to one another. In other words, for example, all of the even or all of the odd word lines are connected to one another so that a parallel driving of the gates of a series of test structures can be performed. The equivalent circuit diagram shown in Figure 2C clearly illustrates that in either pair of transistors, for example 220 and 222, the transistors always operate serially.

[0023] Whereas in the above-described circuit arrangement illustrated in Figures 2A - 2C, by way of example, two laterally offset vertical selection transistors are connected to one another back to back by a test structure, an exemplary embodiment of the present invention in which a test structure connects a larger number of vertical selection transistors in chain form will now be described with reference to Figures 3A and 3B.

[0024] Figure 3A depicts, similarly to Figure 2A, a section of a transistor array with vertically arranged active webs (AT) 300 and a metal plane M0 which lies horizontally and forms a bit line. Figure 3A likewise shows the layout representation of a buried strip (BS)304, which forms drain electrodes of vertical selection transistors at the intersection of the BS shape with deep trench 306 and active web 300. As shown in Figure 3A, deep trench 306 has the form of a zigzag strip. The chain formed by the integrated test structure depicted in Figure 3a connects ten transistors to one another. Two outermost additional vertical selection transistors serve as left-hand and right-hand complex drain terminal E, A. The integrated test structure illustrated in Figure 3A thus enables the necessary access for measurement purposes to the buried structures (for instance at the drains) of the vertical selection transistors, with separate currentless and current-carrying access. For the sake of better clarity, the word lines are omitted in Figure 3A, even though in reality they lie parallel to the active webs AT. Deep trench 306 running in zigzag form is composed of diagonal DT sections which, in principle, are formed in the same manner as described above with reference to Figures 2A and 2B. Figure 3B shows the equivalent circuit diagram of the test structure illustrated diagrammatically as a layout in Figure 3A. The long zigzag DT comprises the sections 306a to 306l and connects twelve vertical selection transistors 308a to 308l, the ten inner ones of which form the test object (DUT). Vertical selection transistor 308a on the outer left forms left-hand terminal E. Vertical selection transistor 308l on the outer right forms terminal A. All the source terminals are routed toward the outside through CB 310 (source contacts to the bit line). A bit line formed by the metal plane M0 is common to all the source

terminals of the ten selection transistors 308b - 308l that are to be tested by the test structure, while the CB terminals for the FET selection transistors 308a and 308l on the left and right are embodied separately.

[0025] In another embodiment of the present invention, a test structure has a plurality of chains each having a different number of selection transistors that are connected to one another, where the respective number of the FET selection transistors connected to one another by the test chains are significantly different between different chains. Thus, by way of example, in each case 2, 10, 80 etc. vertical selection transistors may be connected to one another in different chains.

[0026] As already explained with reference to Figures 3A and 3B, in embodiments of the present invention selection transistors are connected to one another by the test structure according to the invention may be connected either in series or in parallel with one another by connection of corresponding word lines and bit lines. The transistor test chain illustrated in Figures 3A and 3B also permits the evaluation of the properties of vertical FET transistors 308a and 308l on the outer left and right, which act as complex drain parts, since said transistors can influence the measured values of the vertical FET transistors that are connected to one another and are the prime object of measurement. In particular, by measuring the properties of test chains having a different number of connected vertical FET transistors, it is possible to identify an offset attributable to these outer connection transistors.

[0027] By driving high word lines 312a and 312l of the transistors 308a and 308l, respectively, the latter are opened and thus permit a detection of leakage currents into

buried strips 304 and into diverse semiconductor junctions in the vicinity of the buried strips 304.

[0028] In preferred embodiments, the test structure described above has a second connecting means for the common connection of the source electrodes of the selection transistors encompassed by the test structure, and the second connecting means preferably contain bit line contacts and bit lines of the vertical selection transistors encompassed by the test structure.

[0029] In alternate embodiments of the test structure according to the present invention, two adjacent selection transistors are laterally offset by one cell, or by a plurality of cell units, wherein in each case one deep trench is extended diagonally between two laterally offset vertical selection transistors.

[0030] In another embodiment of the test structure according to the present invention, a multiplicity of vertical, laterally offset selection transistors are connected to one another in chain form by diagonally extended deep trenches, and a plurality of such chains may be present. In this embodiment, it is preferable for the respective number of selection transistors of the individual chains that are connected to one another to be significantly different. The transistors respectively located the furthest on the outer left and right of each chain enable access to the intervening selection transistors to be tested via the first and second connecting means.

[0031] Overall, an integrated circuit arrangement equipped with such a test structure enables the measurement and the evaluation of leakage currents at different semiconductor junctions, a measurement and evaluation of capacitances and overlap

capacitances between different sections of the integrated circuit arrangement, and also a stress test for determining the reliability of the entire integrated circuit arrangement.

[0032] The foregoing disclosure of the preferred embodiments of the present invention has been presented for purposes of illustration and description. It is not intended to be exhaustive or to limit the invention to the precise forms disclosed. Many variations and modifications of the embodiments described herein will be apparent to one of ordinary skill in the art in light of the above disclosure. The scope of the invention is to be defined only by the claims appended hereto, and by their equivalents.

[0033] Further, in describing representative embodiments of the present invention, the specification may have presented the method and/or process of the present invention as a particular sequence of steps. However, to the extent that the method or process does not rely on the particular order of steps set forth herein, the method or process should not be limited to the particular sequence of steps described. As one of ordinary skill in the art would appreciate, other sequences of steps may be possible. Therefore, the particular order of the steps set forth in the specification should not be construed as limitations on the claims. In addition, the claims directed to the method and/or process of the present invention should not be limited to the performance of their steps in the order written, and one skilled in the art can readily appreciate that the sequences may be varied and still remain within the spirit and scope of the present invention.